Time screening optimization algorithm for ROSAT PSPC/HRI observations

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Abstract. ROSAT PSPC/HRI observations are characterized by intervals with significant background count-rate enhancements mainly due to particles or solar scattered radiation. We have developed an algorithm for time screening PSPC/HRI observations in order to maximize the signal to noise (SNR) ratio of faint point-like sources. The algorithm parameters have been optimized with tests on real and simulated data. In the case of a crowded PSPC field pointed to the Pleiades open cluster, a typical SNR gain of $\sim 20\%$ with respect to the unscreened case is obtained for faint sources with a cut of 6% of the total exposure time. This algorithm although presently tailored for the ROSAT PSPC/HRI observations can be easily generalized to the analysis of other X-ray detectors' data.

1. Introduction

We describe a procedure to screen out the high background intervals from X-ray observations done with the ROSAT PSPC or HRI. Aim of this screening procedure is to find a trade off between minimizing the excess background and maximizing the accepted time interval, in order to maximize the signal-to-noise ratio of the sources. Our approach differs from previous recipes suggested from Snowden et al (1992, S92 hereafter, 1993) because it is **model independent**. We do not attempt to model the physical origin of the background contributions, but we try to eliminate them on the basis of their effect on the signal-to-noise ratio (SNR) of point sources in the field of view. Despite the generality of the algorithm, in this paper we will focus on parameter optimization for the PSPC case only. The HRI case have similar parameters. The two major anomalies in the background light curve of *ROSAT* data, namely high particle background and short term enhancements, are considered separately.

2. High Particle Background

Studying a PSPC pointed observation of the Vela supernova remnant (Bocchino, Maggio & Sciortino 1994), we have verified that the PSPC dead-time is negligible up to Master Veto (MV) count-rate = 250 cts/s, which corresponds to a residual accepted PSPC particle background count-rate $\leq$ 1.3 cts/s (S92), to be compared with the minimum and typical PSPC cosmic background rate of $\sim$ 5 cts/s and $\sim$ 12 cts/s, respectively. At higher MV count rates, significant dead time of the PSPC electronics occurs, resulting in a drop of the accepted X-ray events count-rate. On the basis of these considerations, we have decided to retain all observation intervals where the MV count-rate is below 250 cts/s. This choice is not very restrictive in terms of rejected time ($\leq$ 1% according to S92) and avoids including observation intervals with critical dead-time. Our threshold of 250 cts/s sets an upper limit to the relative contribution of the particle component to the total PSPC background equal to 25%, with a more typical value of 10%. We have verified that adopting the S92 threshold (170 cts/s) yields a significant cut of the exposure time and a systematic decrease of point sources SNR.

3. Short term enhancements

A typical background light-curve of a ROSAT PSPC or HRI observation (Figure 1a) is characterized by occasional steep enhancements in total accepted event count-rate. Most of them are due to solar radiation (including possible flares) scattered by the Earth atmosphere (Snowden et al 1994). In order to obtain an "optimal" screening, we maximize a function (hereafter *efficiency function*, E) defined as the ratio of a faint source signal to noise ratio (SNR) computed in a time screened observation $(SNR)_s$ and in the entire unscreened observation $(SNR)_u$. The following formulation is very general with respect to the choice of the detection cell geometry, and it does not depend on the physical model of the background contaminations. The following quantities refer to a given source (hereafter the sample source, SS):

C = total counts in the detection cell (DC, measured);
T = total counts in the background cell (BC, measured);
S = source counts;
B = background counts in the DC;
α = fraction of source counts in the DC;
β = fraction of source counts in the BC;
r = ratio of the BC to DC area.

The Unscreened Signal-to-Noise Ratio. We can thus write, following the recipe of Harnden et al. (1984) and Kashyap et al. (1994):

$$C = \alpha\ S + B \tag{1}$$

$$T = \beta\ S + r\ B \tag{2}$$

With simple algebra we can obtain from equations 1 and 2 an expression for the source counts and its error (by propagation of Poissonian noise of C and T), and, therefore, the $(SNR)_u$:

$$(SNR)_u = \frac{S}{\sigma_s} = \frac{S(r\alpha - \beta)}{\sqrt{S(\beta + r^2\alpha) + B(r + r^2)}} \tag{3}$$

The screened SNR and the Efficiency Function. If a fraction x of the total observation time is screened out the expressions for the screened C and T becomes:

$$C_s = (1 - x)\ \alpha\ S + B_s(x) \tag{4}$$

$$T_s = (1 - x)\ \beta\ S + r\ B_s(x) \tag{5}$$

where $B_s(x)$, the total background present in the screened observation ($B(x = 0) = B$, for the unscreened observation). Analogously to what we have done for the unscreened observation we can derive the screened SNR, and then define the efficiency function $E(x, r, \alpha, \beta, S, B)$.

$$E = \frac{(SNR)_s}{(SNR)_u} = \frac{(1-x)\sqrt{(\beta + r^2\alpha) + B/S(r + r^2)}}{\sqrt{(1-x)(\beta + r^2\alpha) + B_s(x)/S(r + r^2)}} \tag{6}$$

In our approach, we have chosen a circular DC and annular BC with the following values $\alpha = 0.9$ and $r = 3$. From the integration of the PSPC point spread function (PSF) at 0.3 keV given by Hasinger et al (1994), we verified that $\beta \sim 0.08$ for off-axis angles in the range $0' - 50'$. The only relevant parameters remain S, and B.

Choice of the sample source The algorithm needs a value for S and B. Since we are more interested in optimal SNR gain for faint sources rather than for the bright ones, we set S equal to the minimum number of counts required to have a statistical significant detection in the field of view. The value of B depends on the choice of the DC radius and therefore on the SS off-axis angle. In order to investigate the dependence of the screening results on B, we run tests with different values of the SS off-axis on simulated data and on a PSPC field of the Pleiades young open cluster with 43076 s total exposure time (rp200068, PI Rosner). We found that the screening is not very sensitive to SS off-axis, because the increase of the detection threshold S that occurs at large off-axis, in some way compensates the increase of B due to a larger DC. On the basis of these results we have chosen to tailor our screening procedure for off-axis $= 30'$ where we have the highest gain in SNR still having acceptable performances of the ROSAT PSPC both in terms of sensitivity and spatial resolution.

Minimization of E(x). The minimization of $E(x)$ is performed on the background light curve of the pointed observation by an iterative process starting at $x = 0$. At each step, a greater temporal cut is performed and $(SNR)_s$ for the SS is computed. The process stops when E starts to decrease.

4. Application to real data

To test the gain in SNR achievable with our screening code, we run the algorithm on the above-mentioned Pleiades PSPC observation. In this case, our algorithm has screened out 2828 sec (about 6% of the entire exposure time). In particular, we applied the Wavelet detection algorithm described by Damiani et al. (1995) to both the unscreened and the screened data sets, and we computed the SNR of the sources detected in both data sets using circular cells and r, α and β as reported in section 3. Figure 1b shows the ratio SNR_u/SNR_s vs. SNR_u of the 93 sources having $SNR_u \geq 2.5$. Beside a statistical scattering of data points, we notice a trend for detections with low unscreened SNR to have a SNR_s/SNR_u ratio greater than one. The median of SNR_s/SNR_u for faint sources ($2.5 \leq SNR_u \leq 6$) is 1.12, whereas not much gain is obtained for brighter sources. This evidence is in good agreement with results of previous test runs showing the advantage of tailoring the algorithm to faint sources.

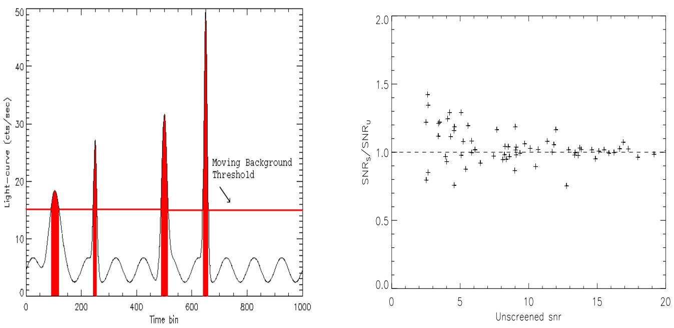

Fig. 1. (a): In this simulated background light curve, the horizontal line is the rejection threshold which maximize E. The shaded areas represent the intervals (and thus background counts) that are screened out. $B_s(x)$ is the integral of the light curve out of the red areas. **(b)**: SNR_u/SNR_s vs. SNR_u for 93 sources detected both in screened and unscreened PSPC observation of the Pleiades open cluster.

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